Advances at the SEMATECH MET at Berkeley

Patrick Naulleau

Lawrence Berkeley National Laboratory

University at Albany

Christopher Anderson

University of California, Berkeley

Kim Dean, Andy Ma

SEMATECH

Paul Denham, Ken Goldberg, Brian Hoef, Dimitra Niakoula

Lawrence Berkeley National Laboratory

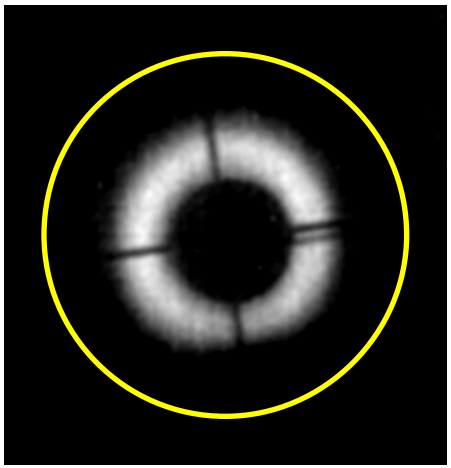
Bruno La Fontaine, Tom Wallow

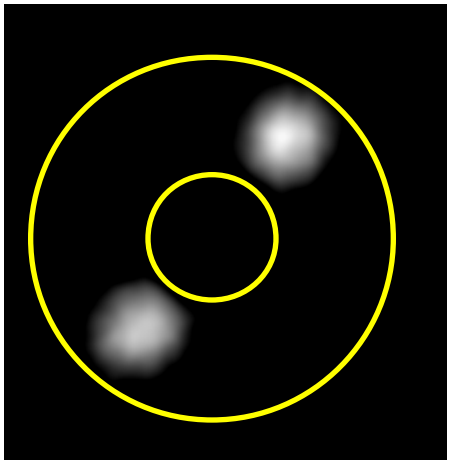
AMD

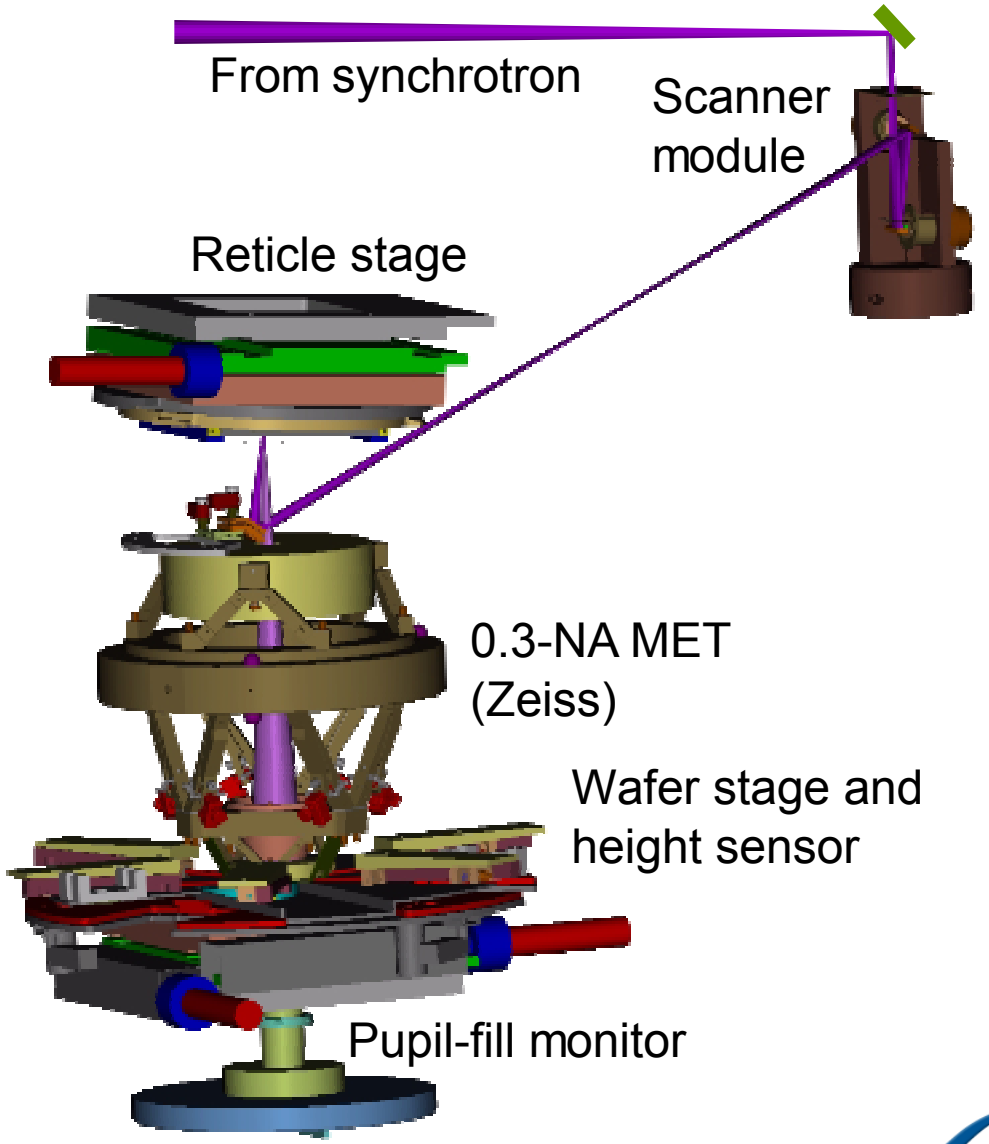
Outline

- System overview and upgrades
- Line-space printing
- Contact printing
- Summary

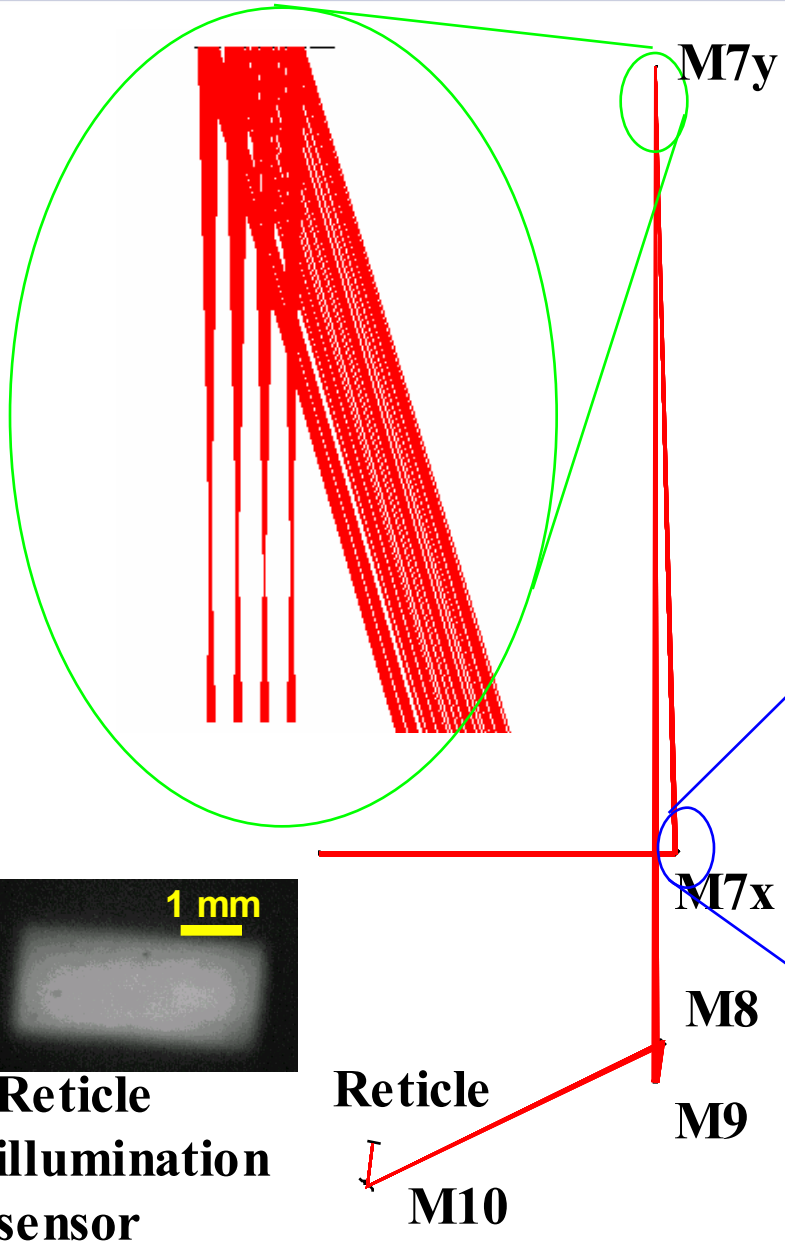
SEMATECH Berkeley EUV MET



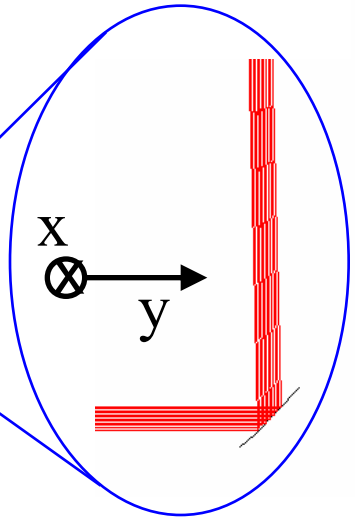


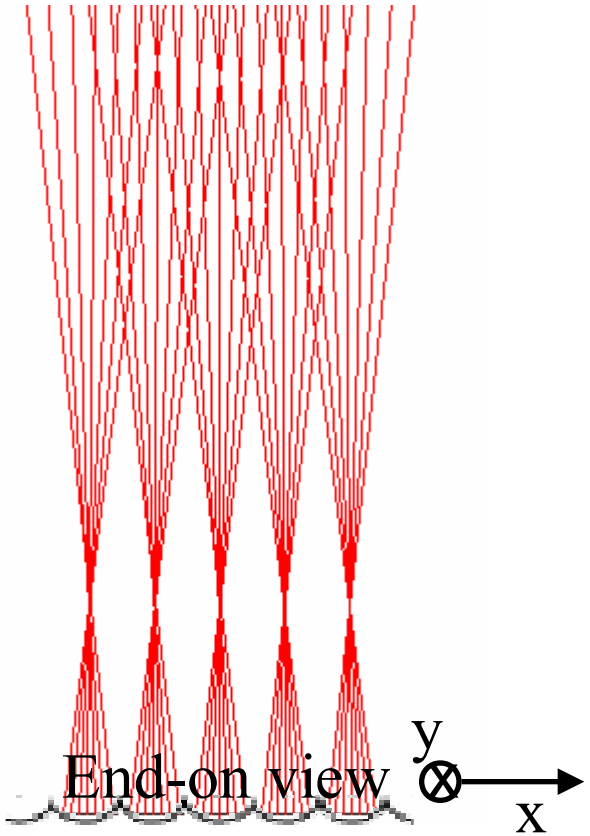


New illuminator improves field uniformity



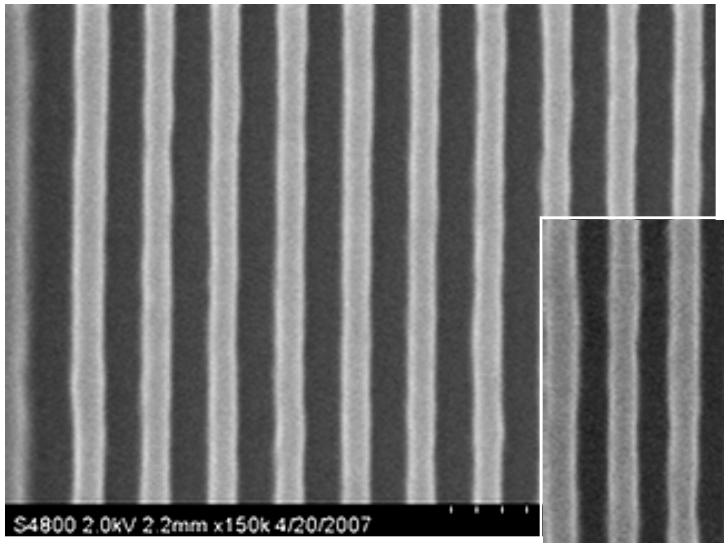
Reticle illumination sensor



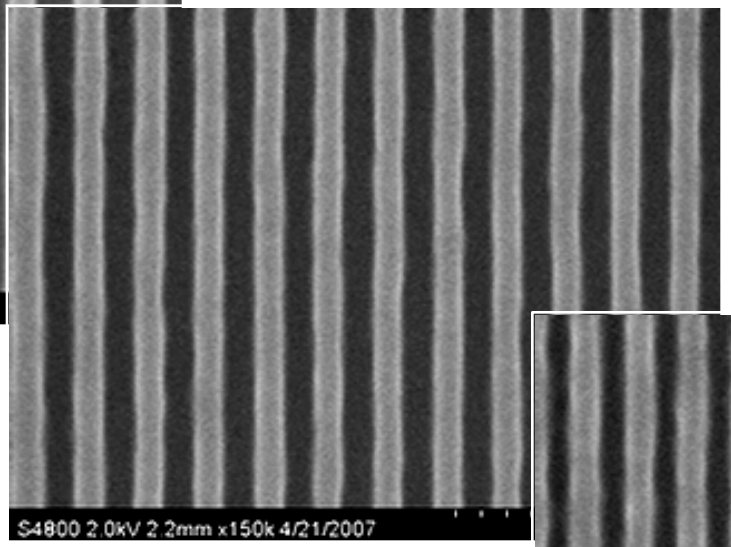


See posters ET-P01, OP-P06

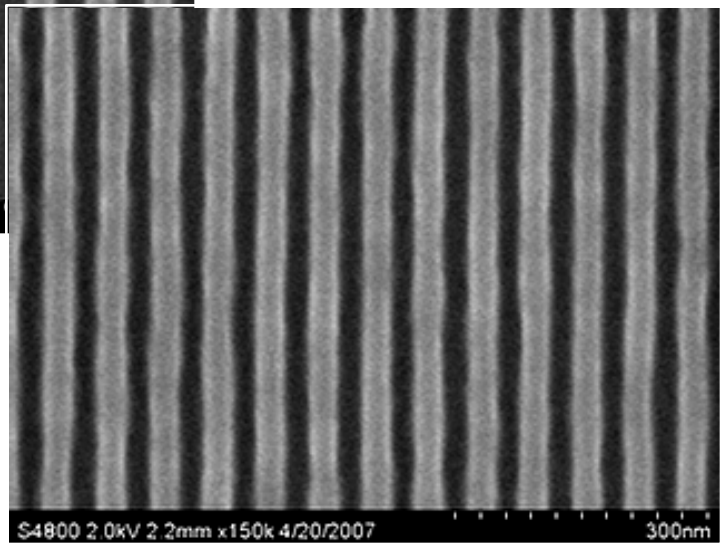
32 nm dense line printing



HP = 40 nm
LER = 2.5 nm
LWR = 3.4 nm



HP = 36 nm
LER = 2.8 nm
LWR = 3.9 nm

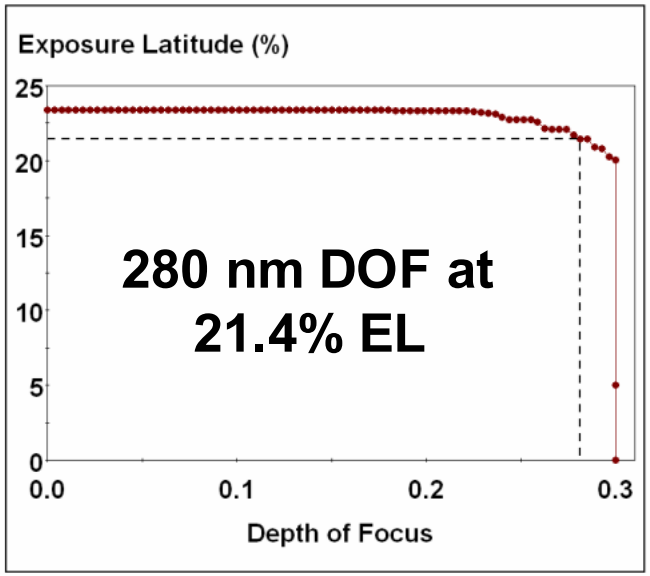


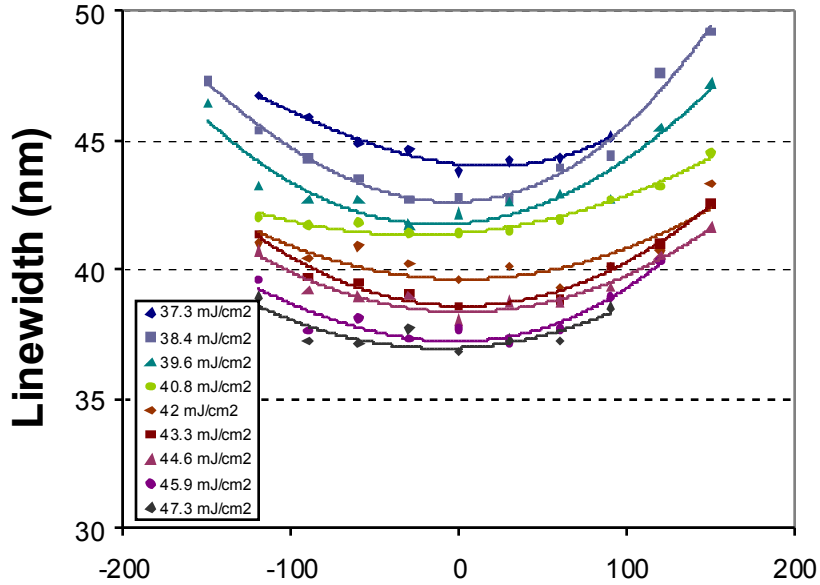
HP = 32 nm
LER = 3.5 nm
LWR = 4.4 nm

Resist J
Sensitivity = 41 mJ/cm^2
LBNL-MET
Monopole

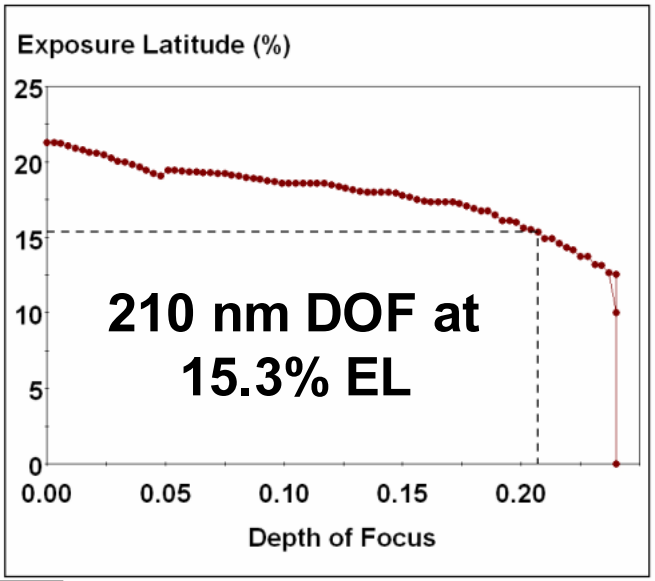
Resist J process windows (40-nm HP)

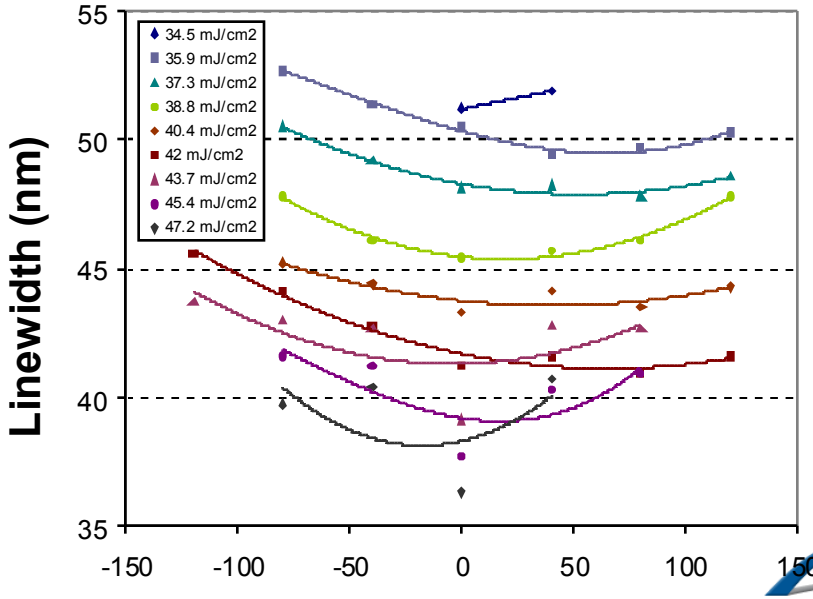
Monopole





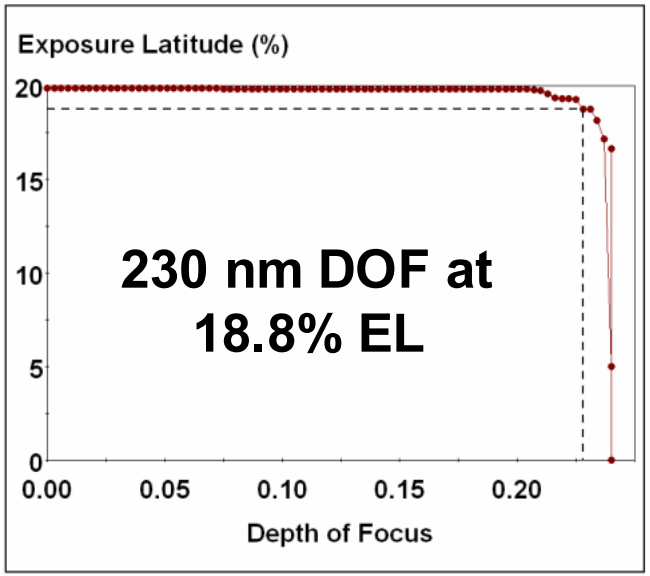
Annular

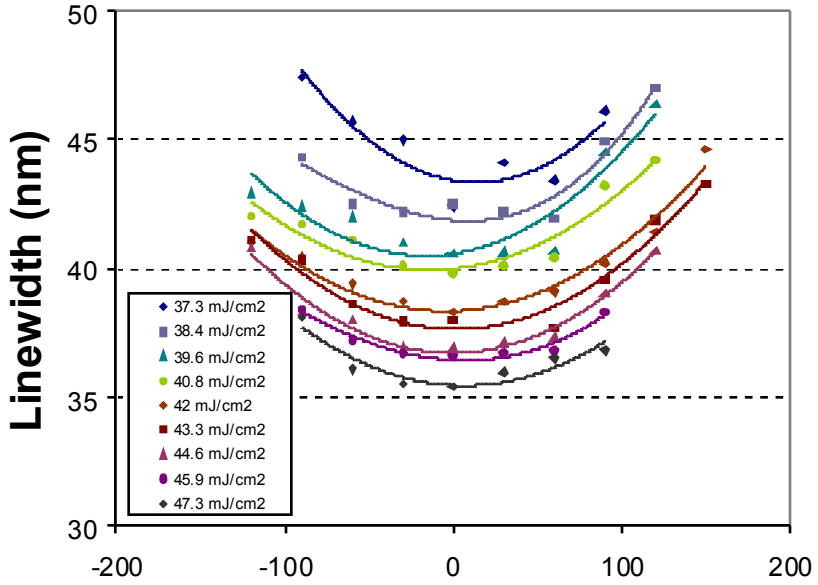




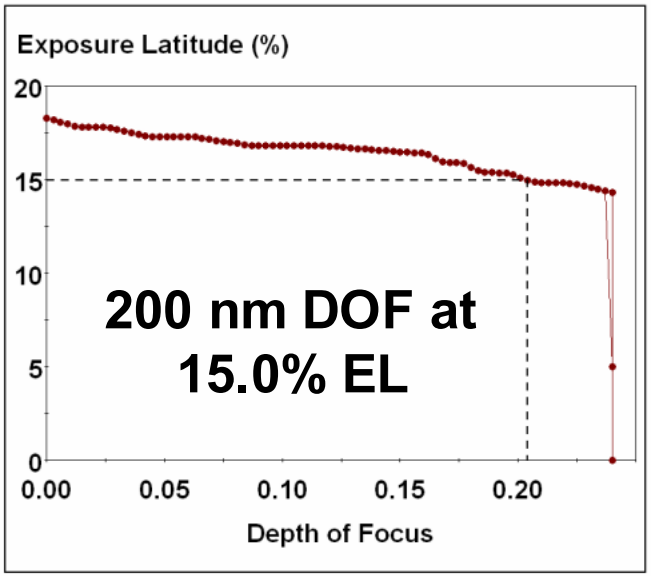
Resist J process windows (36-nm HP)

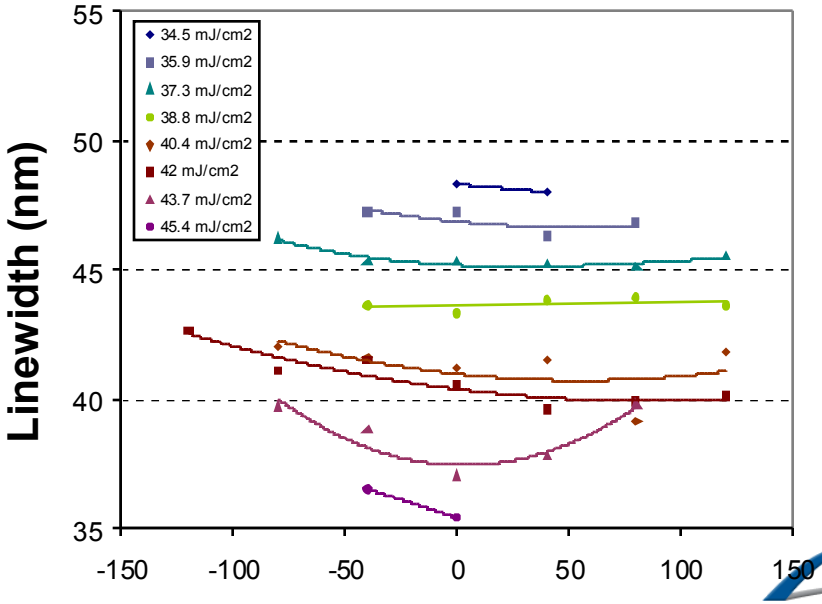
Monopole



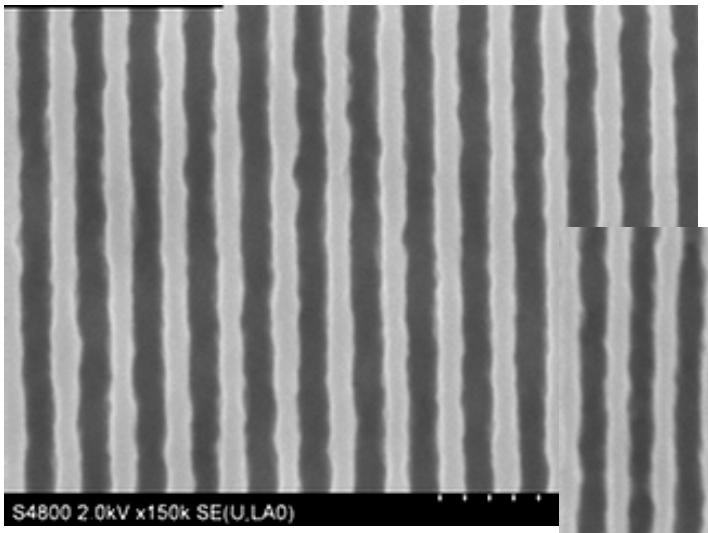


Annular



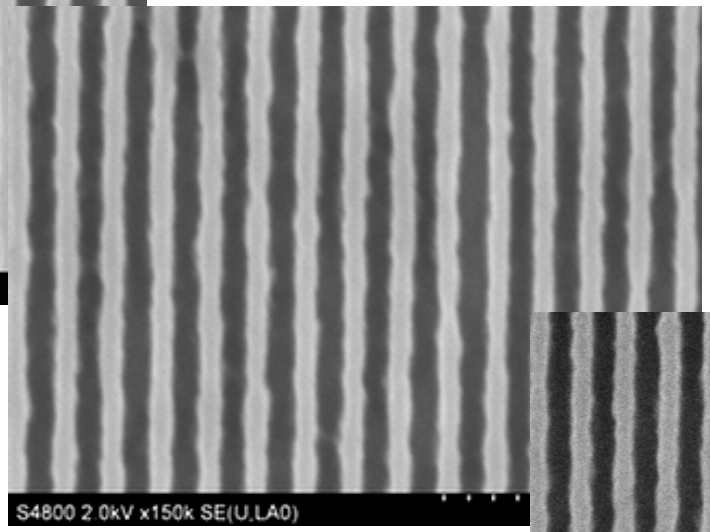


Sub-30-nm dense line printing

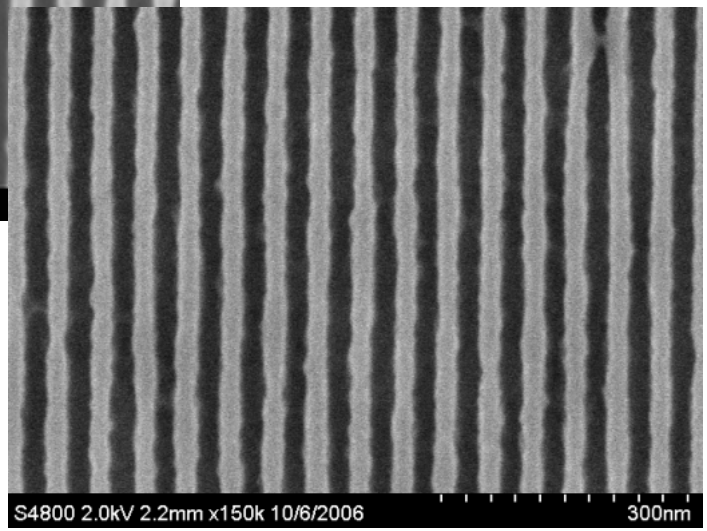


HP = 36 nm
CD = 32 nm
LER = 3.7 nm

Material courtesy of
Hiroto Yukawa, TOK



HP = 32 nm
CD = 28 nm
LER = 4.2 nm

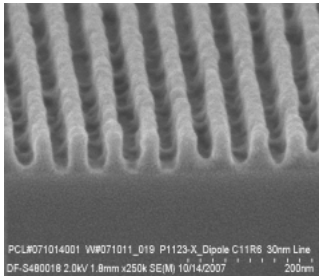
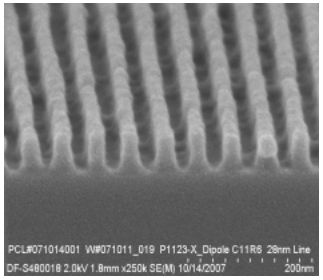
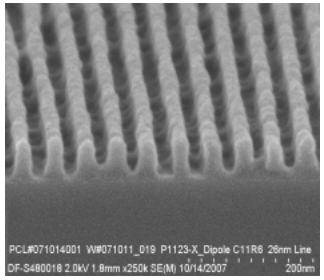
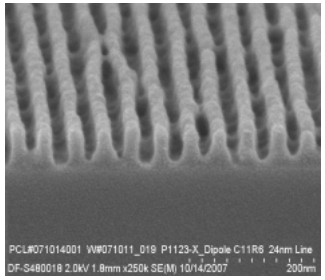


TOK resist
Sensitivity = 12 mJ/cm^2
LBNL-MET
Monopole

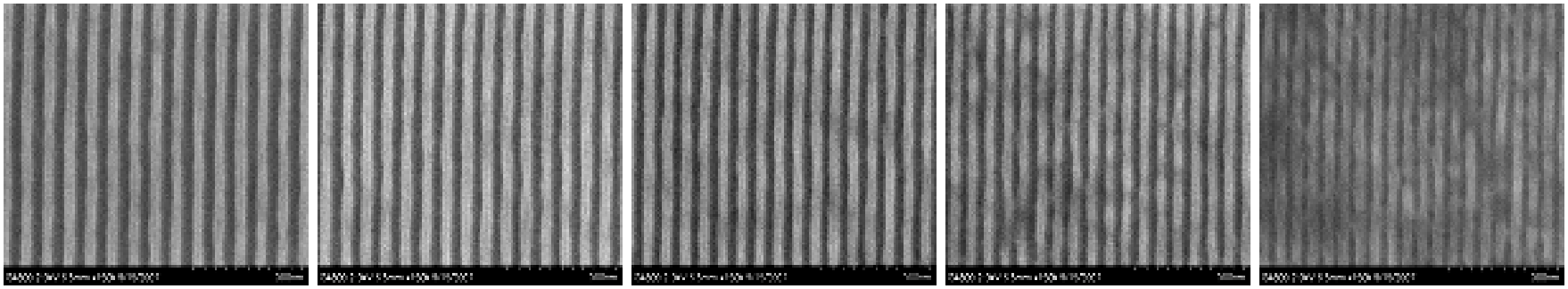
HP = 28 nm
CD = 26 nm
LER = 3.9 nm

Several resists breaking 25 nm barrier

LBNL-MET, dipole illumination

	30 nm HP	28 nm HP	26 nm HP	24 nm HP	22 nm HP
Resist E					

Esize @ 30-nm dense = 17 mJ/cm^2, film thickness = 50 nm

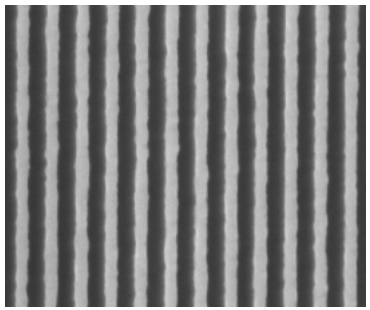
Resist B 

Esize @ 30-nm dense = 24 mJ/cm^2, film thickness = 50 nm

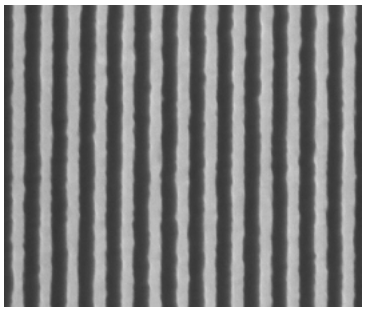
For more details see presentation RE-06 (Andy Ma, SEMATECH) tomorrow

20 nm printing with annular illumination

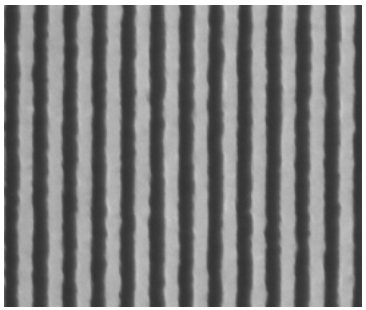
Esize @ 28-nm dense = 30 mJ/cm^2, film thickness = 60 nm



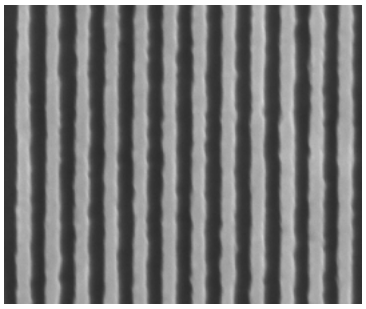
HP=38 nm
LER=3.3 nm



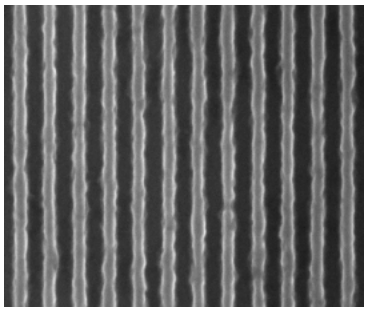
HP=36 nm
LER=3.6 nm



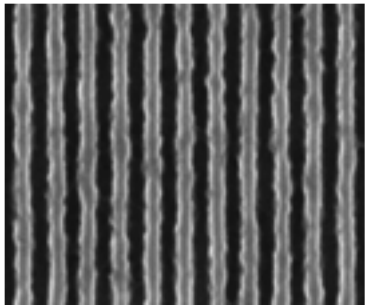
HP=34 nm
LER=3.5 nm



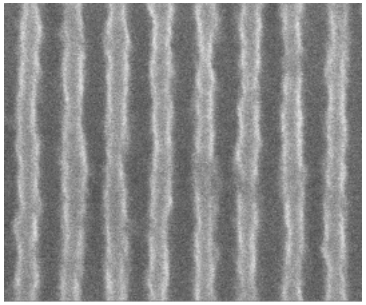
HP=32 nm
LER=3.9 nm



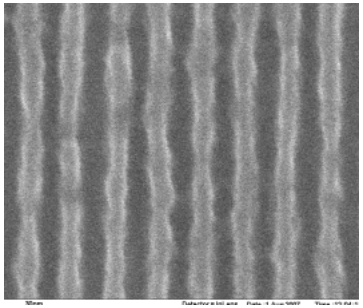
HP=30 nm
LER=4.1 nm



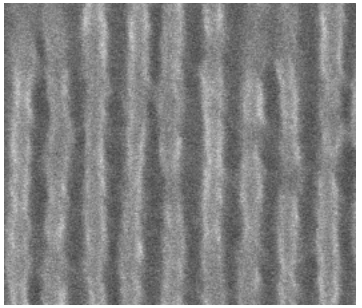
HP = 28 nm
LER=5.5 nm



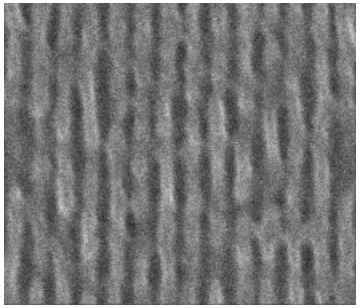
HP = 26 nm
LER=4.8 nm*



HP = 24 nm
LER=5.8nm*



HP = 22 nm
LER=6.2nm



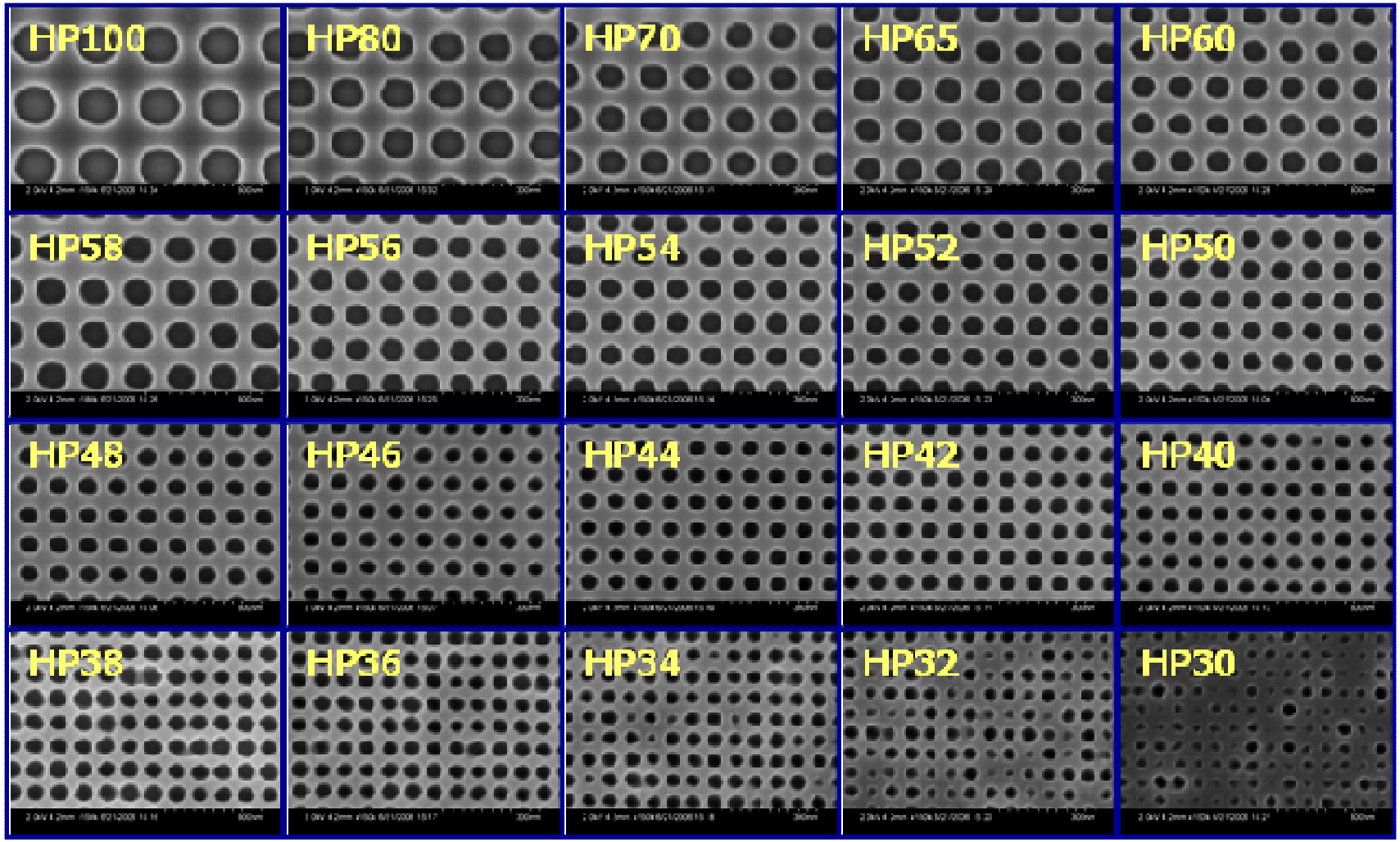
HP = 20 nm

*LER measured over 300-nm instead of 1 μm

LBNL-MET, annular illumination

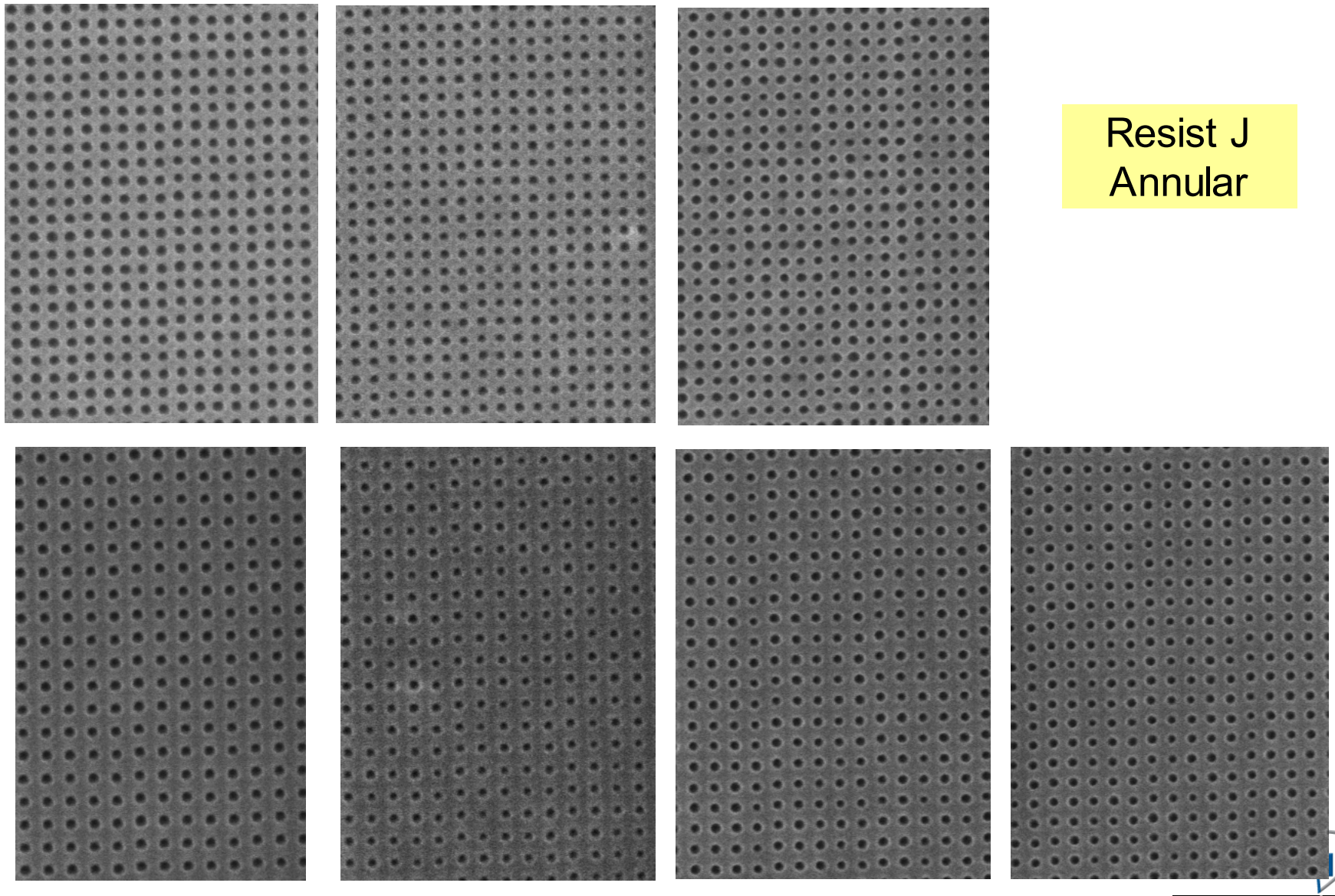
Data courtesy of Seong-Sue Kim, Seyn Lee, Samsung

Contact-hole printing



Data courtesy of Seong-Sue Kim, Samsung

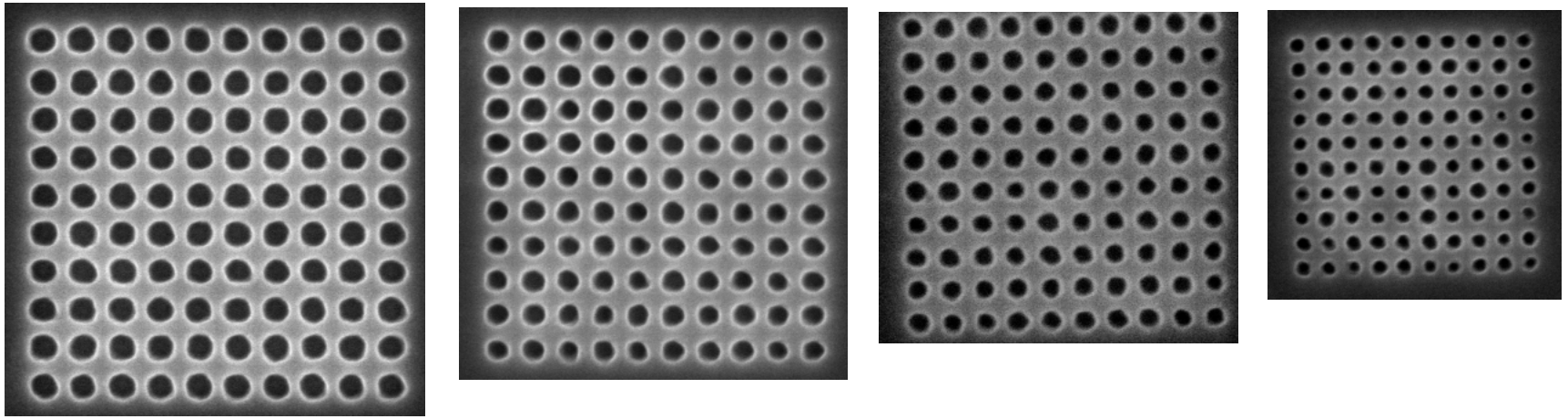
30 nm contacts; E_0 = 15 mJ/cm^2



Dense contacts; E_0 = 10 mJ/cm^2

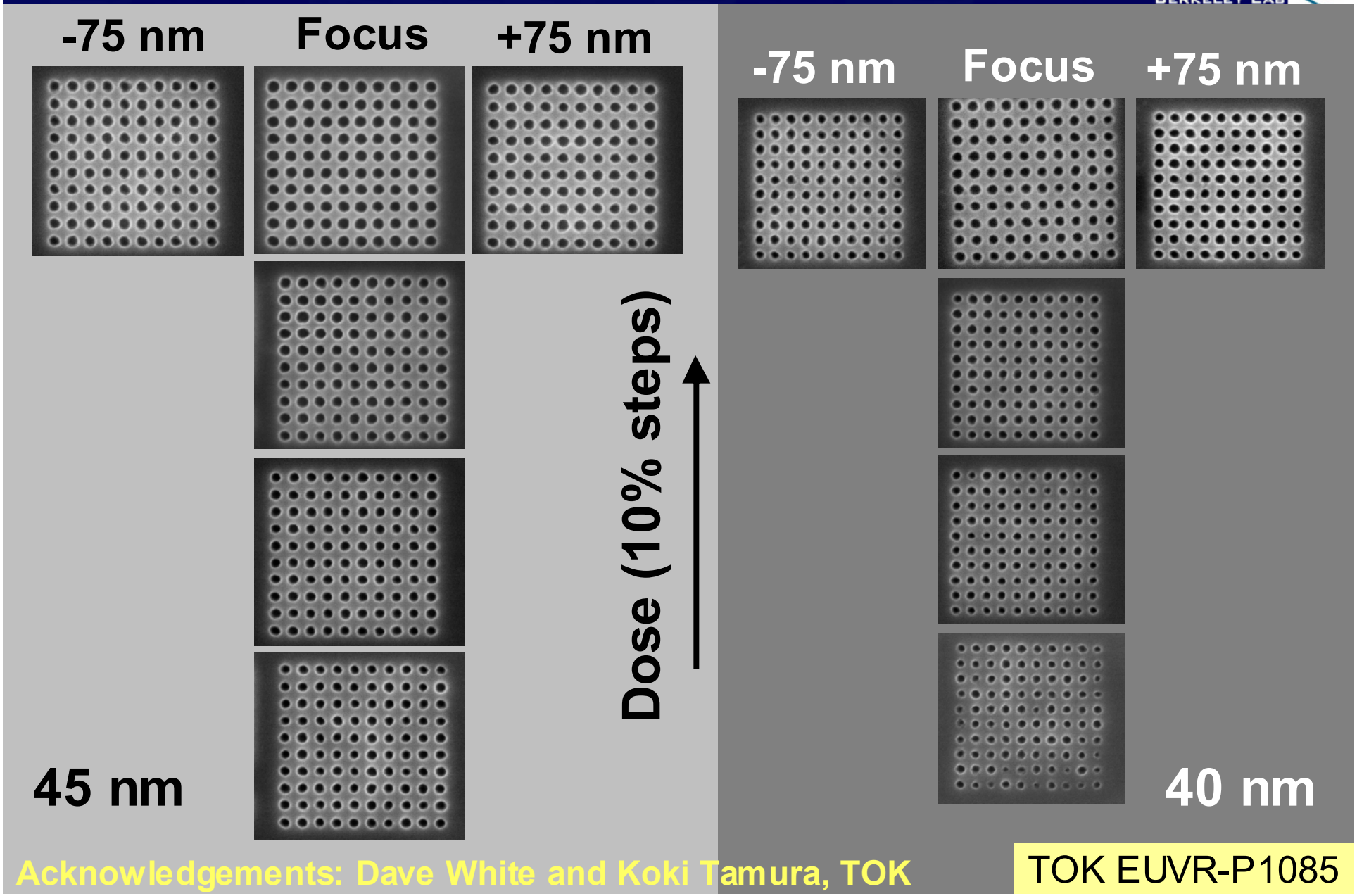
TOK EUVR-P1085
E_0 = 10 mJ/cm^2
Annular

50 nm **45 nm** **40 nm** **35 nm**



Acknowledgements: Dave White and Koki Tamura, TOK

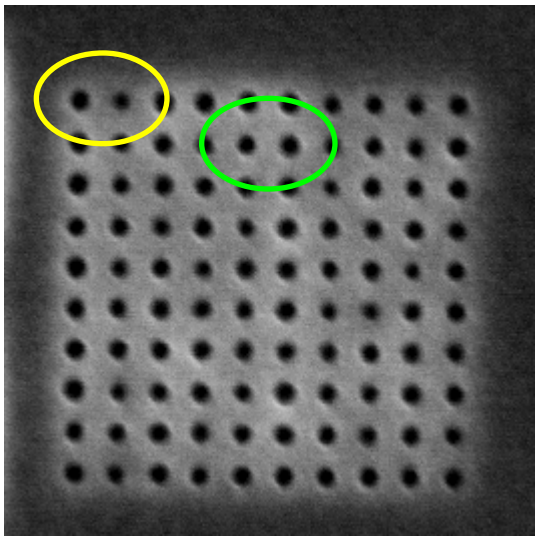
Contacts through dose and focus

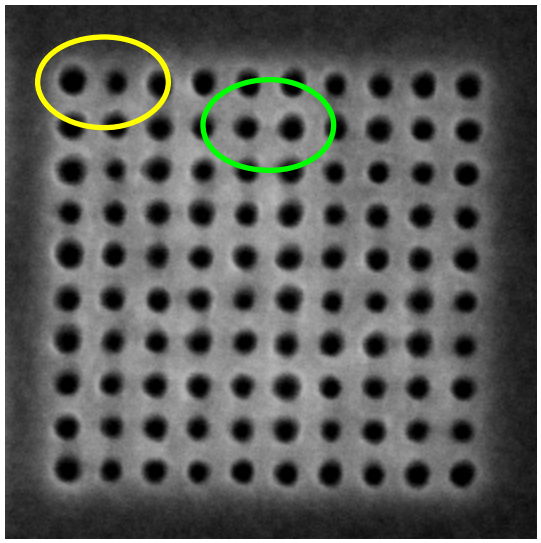


Acknowledgements: Dave White and Koki Tamura, TOK

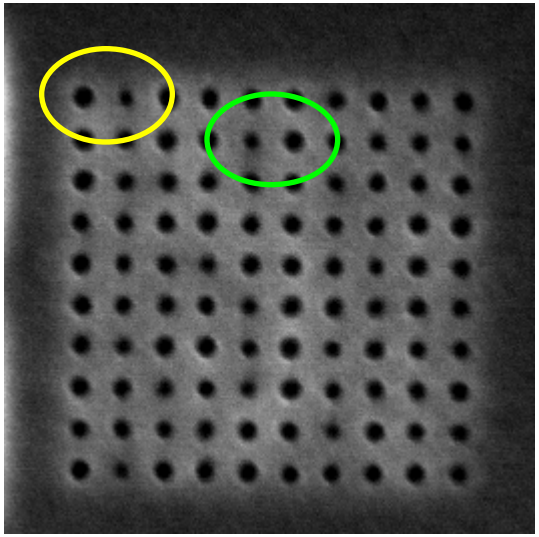
TOK EUVR-P1085

Repeated printing of 35 nm contacts shows variation NOT dominated by photon noise





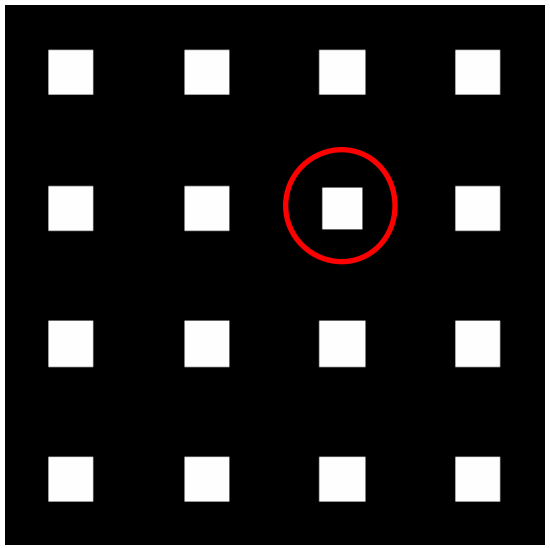
RHEM Resist
LBNL-MET
Annular
E_0 = 10mJ/cm^2



- 35-nm 1:2 contacts
- RMS size variation = 3.2 nm
- Reproducible size variation through dose and focus
- Contact variation must be dominated by mask

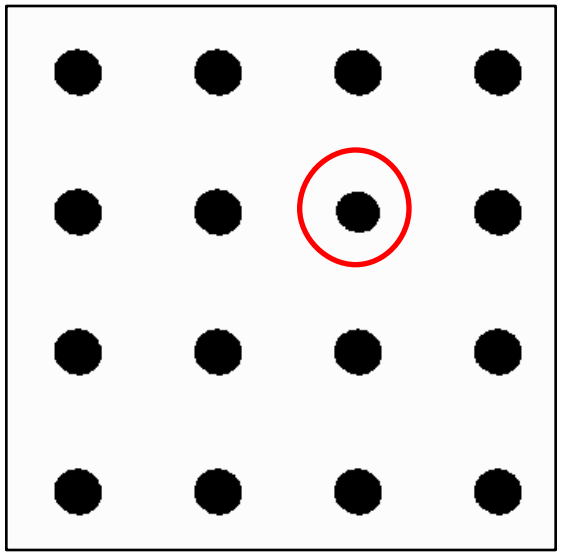
Optical MEEF does not explain observed contact variation

Mask

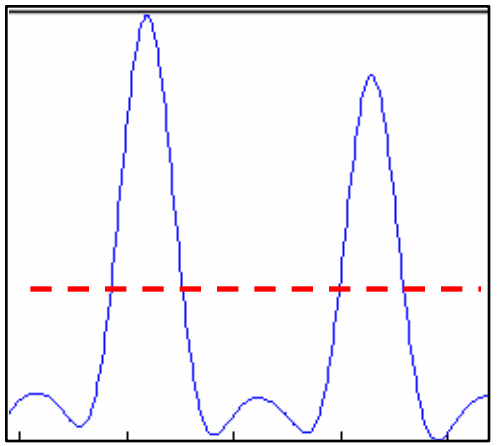


2.8 nm error on
35 nm contacts
(wafer coordinates)
Aerial-image
modeling includes
full EUV wavefront

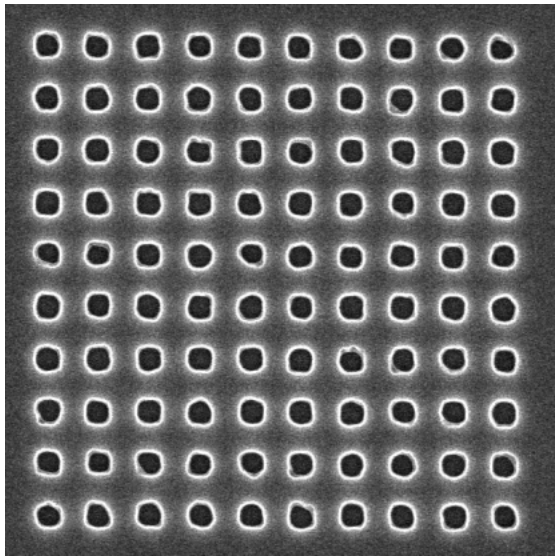
Ideal Resist



MEEF = 1



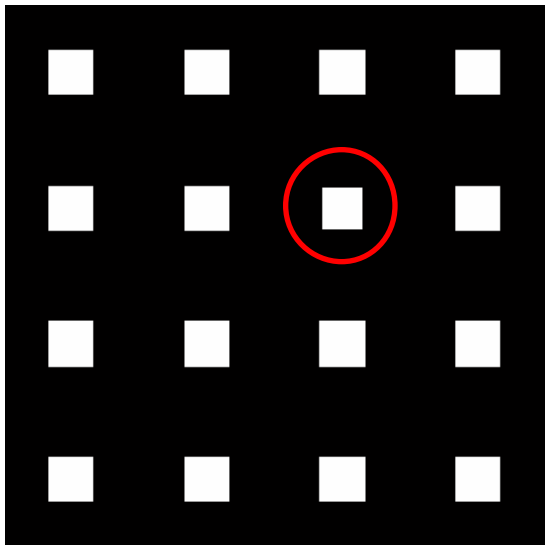
Actual Mask



- 35 nm 1:1 contacts on 5x EUV mask
- RMS 1x diameter variation = 1.1 nm
- Resist var. = 1.1 nm

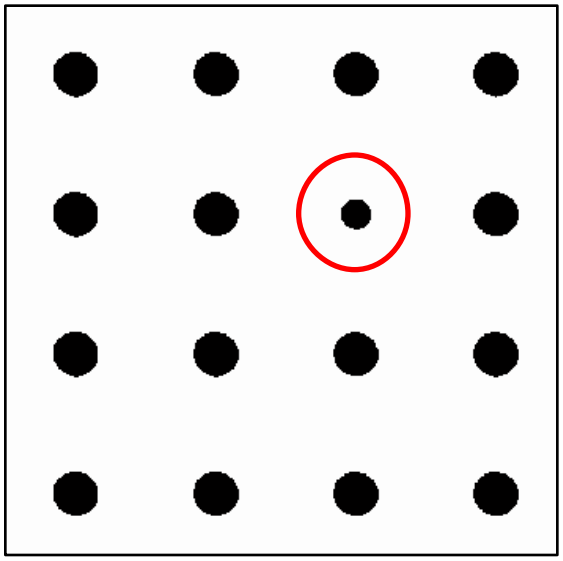
Resist blur dominates MEEF

Mask

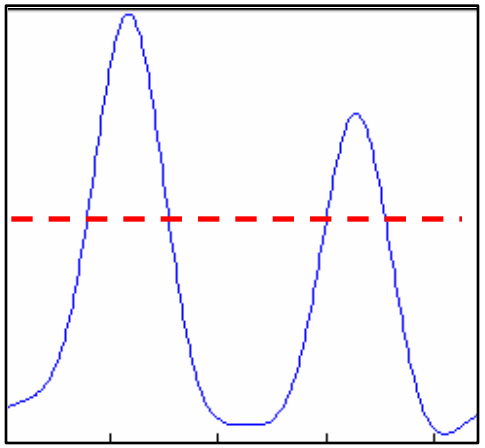


2.8 nm error on
35 nm contacts
(wafer coordinates)
Aerial-image
modeling includes
full EUV wavefront

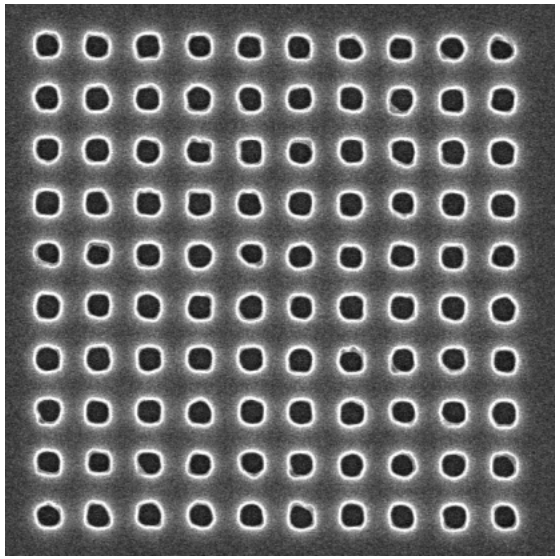
20-nm Blur Resist



MEEF = 3.6

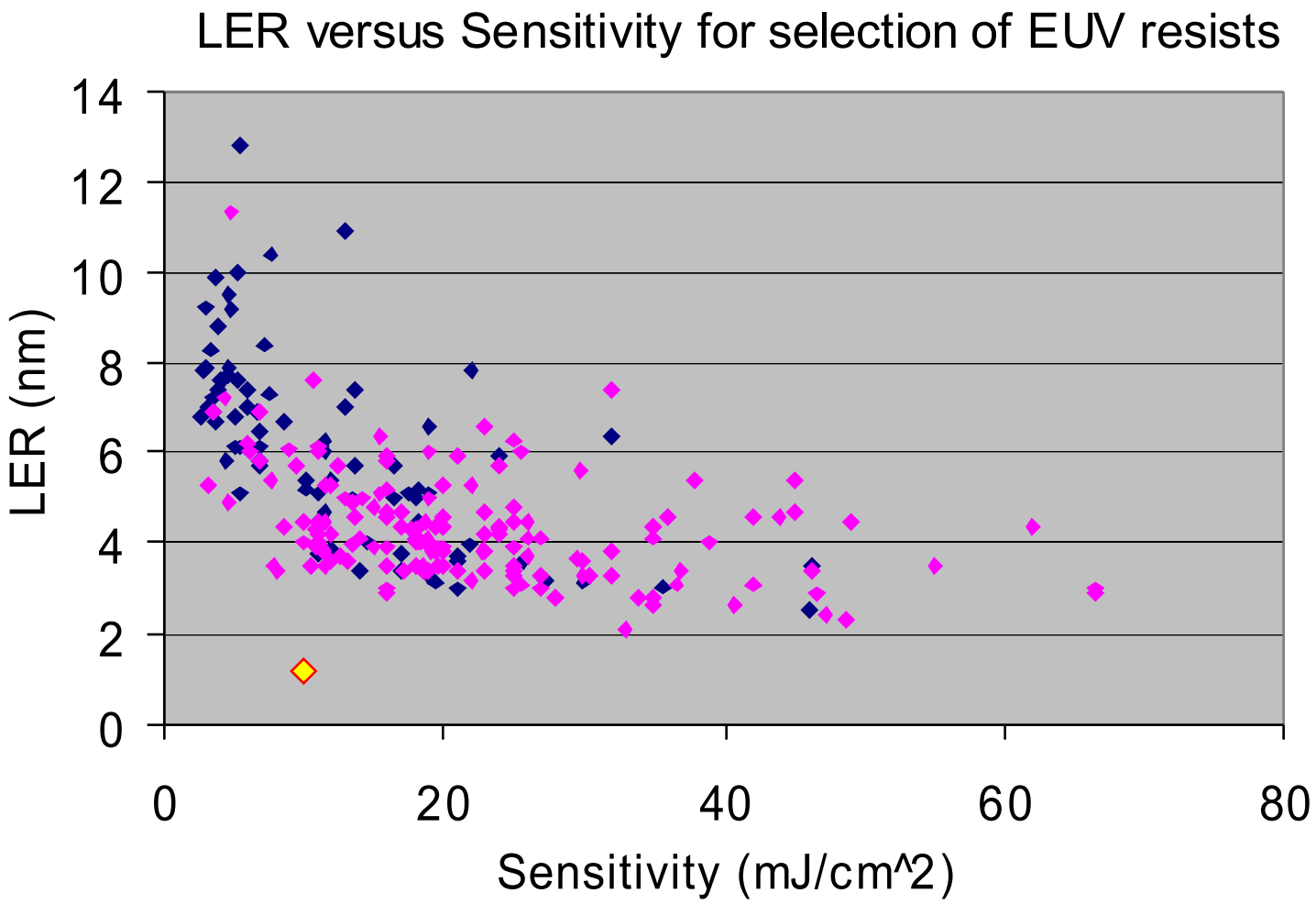


Actual Mask



- 35 nm 1:1 contacts on 5x EUV mask
- RMS 1x diameter variation = 1.1 nm
- Resist var. = 4.0 nm

EUV resist LER & sensitivity



Status: Line Edge Roughness (HVM Spec): < 1.6 nm
Line Edge Roughness (Best Current): 2.4 nm

Summary

- The SEMATECH MET facility at Lawrence Berkeley National Lab provides ultrahigh resolution capabilities from a conventional projection EUV system
  - Enables advanced resist AND mask studies see:
    - MA-03, Ted Liang, Intel
    - DI-03, Gisung Yoon, Samsung
- Illuminator upgrade providing much improved field uniformity has been completed
- Large process windows at 36-nm HP and printing down to 22-nm HP lines and 30-nm 1:1.5 contacts
- Resist resolution limit dominating contact MEEF

Acknowledgments

Kevin Bradley
Stefano Cabrini
Weilun Chao
Jerrin Chiu
Rene Delano
Eric Gullikson
Gideon Jones
Drew Kemp
Seno Rekawa
Farhad Salmassi
Ron Tackaberry
LBNL

Obert Wood
AMD

Bob Allen
Greg Wallraff
IBM

Seong-Sue Kim
Seyn Lee
Samsung

Jim Thackeray
Katherine Spear
Rohm and Haas

Hiroto Yukawa
Koki Tamura
Dave White
TOK

Supported by: SEMATECH